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Energy Storage Considerations for a Robotic Mars Surface Sampler

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ENERGY STORAGE CONSIDERATIONS FOR A ROBOTIC MARS SURFACE SAMPLER

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A Mars Rover capable of obtaining surface samples will need a power system for motive power and to power scientific instrumentation. Several different power systems are considered in this paper along with a discussion of the location options. The weight and volume advantages of the different systems are described for a particular power profile. The conclusions are that a Mars Rover Sample Return Mission and Extended Mission can be accomplished utilizing photovoltaics and electrochemical storage.

INTRODUCTION

Manned exploration of Mars is being proposed by the National Commission on Space for the next century.[1] To accomplish this task with minimal resupply cost for extended stay times, use of Mars' resources is desirable. Therefore, we must send precursor surveying equipment to determine Mars' resources to a greater extent than is now known from previous spacecraft Missions. A 1992 launch is planned for the Mars' Observer that will contribute greater mapping resolutions and to expand the scientific data base. However, the Observer will not be able to ascertain sub-surface resources. A Mars Rover and Sample Return (MR/SR) precursor mission has been identified to accomplish the task of determining surface and sub-surface mineral and chemical resources that will be utilized by future explorers.[2] In addition, geological data of Mars can be obtained to better understand the planet's evolution and possible clues to the history of the solar system. The precise scenario for the MR/SR mission is not defined at present. One scenario is to collect surface mineral samples and drill for sub-surface core specimens. These samples will undergo in-situ analysis and will be stored on the rover and transported to the Earth Return Vehicle (ERV). About 10 kg of samples will be returned for further in-depth analysis. The rover could transverse hundreds of kilometers during 1 year while collecting the samples. At first, the rover will travel short distances to collect samples and safely return them to the ERV. As confidence is developed in rover operations, longer, slightly riskier, terrain could be covered. Once the rover has collected and returned the allotted samples, the ERV will return to Earth and the rover will be left behind to explore high risk terrain near canyons, volcanoes and possibly the polar regions. On-board laser instrumentation could be used to scan and analyze areas of geological interest such as canyon and crater walls not readily accessible to the rover. Data of the Martian globe could be recorded and relayed for many years. The actual rover operations plan for both the sample return and extended mission will have a large impact on rover capabilities and the power system supplying power for transversing and scientific instrumentation.

POWER SOURCE AND CONVERSION

Several power source/conversion and location options for the rover have been identified (Fig. 1). These include power generation on the lander, Entry Vehicle (EV), Mars Orbiter (MO) and on the rover itself. Power from the lander would require the rover to return to the landing site to recharge the energy storage system, which limits rover excursions to one-half the range of the storage capability. Power from the EV or MO could be beamed microwave or laser power converted from photovoltaic cells on the orbiting spacecraft. The probability of advances in this power transmission technology, to increase efficiency and reduce mass may be beyond the mission technology cut-off date of the 1992-93 time frame.

For on-board rover power, a radioisotope thermoelectric generator (RTG) has been considered with energy storage to handle peak power demands. However, the availability of isotopes for NASA's use is in question in addition to high cost, low power density and the politically unfavorable use of radioactive materials.

Another method for power generation on board the rover employs rover-housed deployable photovoltaic arrays and rechargeable energy storage. The array would be deployable for several reasons, which include: (1) larger area than could be body mounted for faster recharge times, (2) sun pointing capability for optimum solar collection; (3) retracted during transversing to increase rover stability and maneuverability, and protection during dust storms, if necessary.

The rover carries its own energy source for (1) motive power, and (2) to perform in-situ scientific analysis. The rover's sampling area is not limited in size by a required return to the landing site for recharge capability.

Rover operation would occur as follows:

Step 1: Deploy array and recharge.

Step 2: Retract array and transverse to next science site, if within range, if not, repeat step 1.

Step 3: Deploy array to power science experiments and recharge.

Fig. 2 shows a graphic representation of the two location options for power generation; (1) fixed and (2) portable.

In addition to motive power the rover's energy storage system must have peaking power capability for high power demand operations such as drilling, coring, instrument operation, steep incline maneuvers and maneuvering out of difficult terrain.

STORAGE SYSTEMS

The storage systems considered in this study are listed in Table 1 along with relevant characteristics; the development status at the present time, the peak power capability of the system and cycle life.

Depending on the driving cycle of the rover, instrument power and reserve power, the power system will require about 1.0 to 5.0 kWh of capacity. The driving cycle profiles will be similar to those used for terrestrial electric vehicles. Extensive work was done between 1975 to 1982 on both lead-acid and nickel-zinc battery systems for electric vehicles sponsored by ERDA at the NASA Lewis Research Center.[3]

However, since battery change-out cannot be considered, battery systems with greater charge/discharge cycle capability (>1000 cycles) will be required for the rover. Both nickel-cadmium and nickel-hydrogen systems have demonstrated many cycles (>10 000) in space use at charge and discharge rates more severe than required for a rover. Therefore, rover operations could span a 5 to 10 year life time. State-of-the-art advancements are continuing to be made projecting energy densities of 40-50 Whr/Kg in the near term, and even higher in the future. Battery assembly techniques using bipolar technology in nickel-hydrogen systems have improved high rate pulse performance, thermal management and battery volume and weight. Prototype batteries of this type have demonstrated 1000's of LEO Cycles that are 1 hr charges/half hour discharges. For example, 8000 cycles on an actively cooled 12.0 V battery and over 1500 cycles on a passively cooled 70.0 V battery. Increases in cycle life can be projected when considering the less demanding rover operating regime.

The fuel cell has traditionally been the power choice for manned space missions because it is compatible with the life support system and has a high energy density. For the rover application one would need to have recharge capability. The regenerative fuel cell was examined for Space Station and both the fuel cell and the electrolyzer have thousands of hours of testing as individual units. However, very limited testing has been done on the two systems operating in a closed cycle unit, referred to as a regenerative fuel cell (RFC).

The regenerative fuel cell with separate hardware for the fuel cell and the electrolyzer is referred to as a dedicated fuel cell system.

Recent studies of fuel cells for GEO missions have examined the possibility of combining the fuel cell and electrolyzer into one set of hardware.[4] This system could be a completely passive system with the advantage of increased reliability. This integrated system is only in the development stage.

Among the other systems considered, Na/S has a high energy density of about 100 Whr/kg. It is at the prototype stage of development and could be a candidate for a Mars Rover when developed to its full potential.

The reversible lithium systems and the bipolar lead-acid system are in the laboratory demonstration stage of development and are not considered viable for the proposed technology cut-off date.

ROVER CHARACTERISTICS

Several design options for the rover can be considered depending on the final scenario of the MR/SR mission. The most reliable scenario, with a small increase in versatility over Viking, would involve a small tethered rover that would receive power and control commands via its umbilical cord. The rover's

limited range would tend to increase the lander's capability to touchdown in higher risk terrain that may accompany a potentially rewarding site selection. In addition, the rover would always find its way back to the lander by following its cord.

Untethered rovers will require a high level of sophistication to accomplish a more ambitious mission.

POWER PROFILE

The power profile considered for this study is shown in Fig. 3 for the PV/storage option. This scenario allows the rover 8 hr of traversing and scientific study, 8 hr of scientific study while immobile and 8 hr for recharging the energy storage system. The total rover power demand was 500 W of which 150 W was used to power the scientific instruments. As noted on the figure, the rover operations could be segmented over several days.

TRADE STUDY ANALYSIS AND RESULTS

Two different power system options were evaluated in this paper. One option consisted of an RTG/energy storage device, where the energy storage was used to provide power for peaking and load leveling. The second one consisted of a photovoltaic array (PV)/energy storage power system where storage is used for motive power. Only storage systems with demonstrated cycle life, peaking capabilities and those that might be available by the technology cut off date were evaluated. These were compared for each power system design and then the two power systems were compared for the advantages and disadvantages of each particular design with respect to total system weight and volume.

Average energy densities were used for the storage systems, since the particular elements of the design have not been established at this point. The energy densities are shown in Table 1. A deployable Galium-Arsenide (GaAs) solar array was used as the basis of comparison with an average power density of 110 W/m^2 and 10 kg/kW. A state-of-the-art RTG with a 250 W power output and a total system weight of 55 kg was used.

A total storage capability of 2 kWh was required for the RTG/storage system. For this small storage capability only batteries were considered. The results of the total system weight and volumes for the different storage systems are shown in Figs. 4 and 5. The preliminary analysis shows that Sodium-Sulfur (Na-S) has the lowest total weight and highest volume while the Advanced Nickel-Cadmium (NiCd) has the lowest total volume but highest weight. To reduce both system weight and volume concurrently, the bipolar nickel-hydrogen ($Ni-H_2$) battery would be the storage system of choice.

The PV energy storage power system option needs to provide 5.2 kWh of storage. This higher storage capacity makes it viable to include regenerative fuel cells as part of our studies. To calculate the total array size and weight, the efficiencies of the storage systems were taken into consideration. This accounts for the substantially heavier solar array needed when fuel cells are used. The results show (Figs. 4 and 5) that fuel cells will offer definite weight and volume advantages over any other storage system considered. A fuel cell system results in over a 50 percent weight and volume savings. Looking

at the other storage systems, the previously found trends were maintained with the bipolar NiH_2 being the next overall system of choice.

When the two power systems are compared the PV/storage system could provide a lighter weight yielding a 30 percent weight savings. It will also provide a total overall lower volume with a 40 percent reduction when the system is optimized for both weight and volume. Other system advantages and disadvantages should be considered when a more detailed analysis is performed taking into account the integration, single point failure reliability issue, safety and complexity of these two power systems.

CONCLUDING REMARKS

The power system options examined in this paper for a MR/SR mission shown that there are certain weight and volume advantages associated with specific systems.

For the RTG/storage system the bipolar nickel-hydrogen battery and the sodium-sulfur battery are both candidates for storage. The bipolar nickel-hydrogen technology is further advanced, more than 8000 LEO Cycles have been demonstrated at the battery level along with peak power capability of 25C. The bipolar nickel-hydrogen storage occupies 35 percent less volume than the sodium-sulfur battery, while increasing the system weight by only 8 percent for the same power level. It also has the benefits of low temperature operation and less complexity.

For the PV/storage system, the fuel cell and the bipolar nickel-hydrogen battery are the primary candidates for storage. The fuel cell becomes a more weight and volume efficient option as rover transverse time exceed several hours. Rover power system requirements must be finalized so that hardware development can be initiated on system components to meet the mission schedule. The bipolar nickel-hydrogen battery is at the prototype technology level while the integrated fuel cell is at the beginning of a development program.

The MR/SR and extended mission can be accomplished utilizing photovoltaics and electrochemical storage.

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3. Energy Research and Development Administration CONS/1011-1 NASA TM-73756 State-of-the-Art Assessment of Electric and Hybrid Vehicles, 1977.

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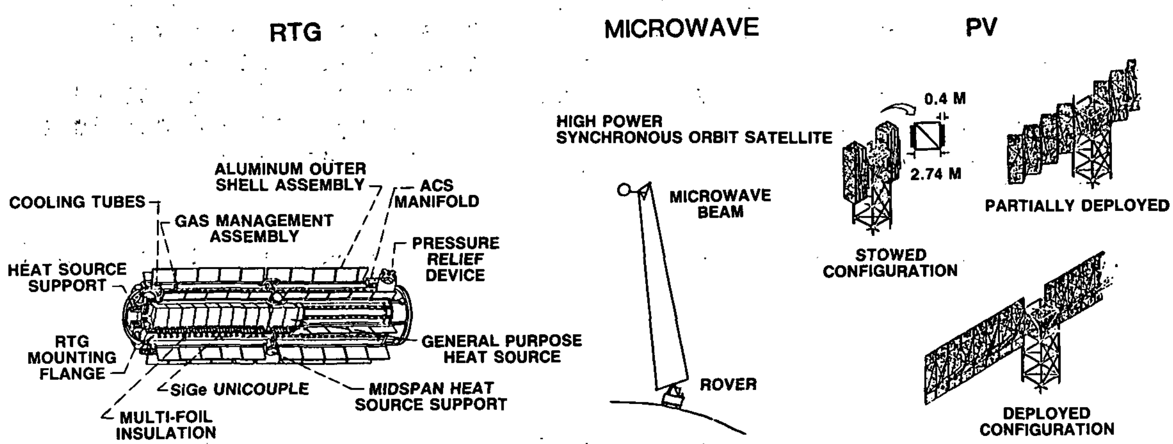
TABLE 1. - STORAGE SYSTEMS CHARACTERISTICS

Storage	Specific energy, Wh/kg	Volume density, L/kW	Efficiency, percent	Cycle Life	Development stage	Peak power capability
Ni-Cd				Long at	Flight qualified	Moderate
SOA	28	43	80	Low DOD		
ADV	28	43	80	Long	SOA	Moderate
Ni-H2						
IPV	45	67	80	Long	Flight qualified	Moderate
Bipolar	50	47	82	Long	Prototype	High
Ag-ZN	90	7	85	Low	Flight qualified	High
Li-XS	100	27	60	Low, none Demonstrated	Demonstrator	Low
Na-S	120	75	85	Low	Prototype	High
$PbSO_4$ Bipolar	50	43		Low, None Demonstrated	Demonstrator	High
REGEN. FC						
Dedicated	190	78	55	Long	Prototype	High
Integrated	120	75	55	None Demonstrated	Development	High



RTG
- SAFETY CONCERNS
- AVAILABILITY
- COST
- WEIGHT

MICROWAVE
- EARLY DEVELOPMENT STAGE
- SUPPORT ELEMENT
- LOW EFFICIENCY
- TRACKING
- SAFE
- IMPRACTICAL FOR ROVER POWER LEVEL

PV
- DEPLOYABLE
- HIGH EFFICIENCY
- HIGH SPECIFIC POWER
- SAFE
- SUSCEPTIBLE TO DUST COVERAGE

	RTG	MICROWAVE	PV
EFFICIENCY %	6	2	25
SPECIFIC POWER Kg/Kw	220	TBD	8
SPECIFIC VOLUME l/Kw	340	TBD	35

FIG. 1. - POWER SOURCE/CONVERSION.

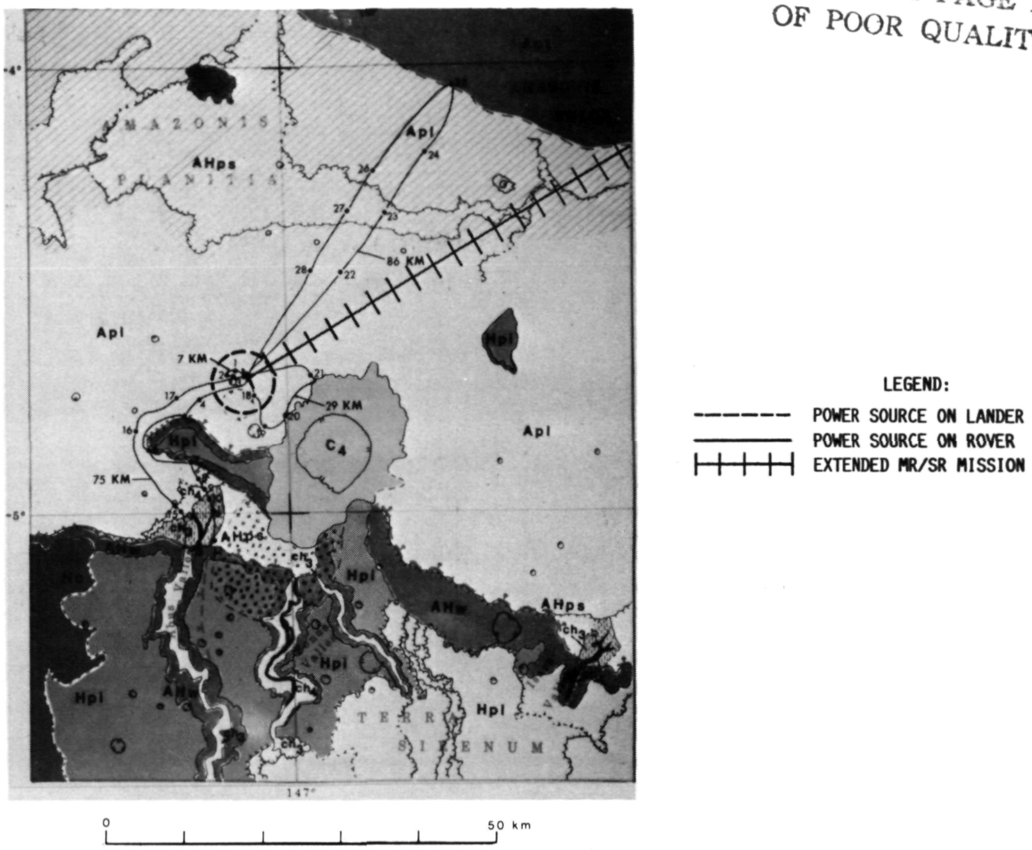


FIG. 2. - ROVER TRAVERSING OPTIONS BASED ON POWER SOURCE LOCATIONS.

SCHEDULE

0 - 8 HR - RECHARGE ENERGY STORAGE

8 - 16 HR - TRAVERSE ROVER ON ENERGY STORAGE

16 - 24 HR - OPERATE SCIENTIFIC INSTRUMENTATION ONLY

NOTE: ROVER OPERATIONS AS SHOWN COULD BE SEGMENTED OVER SEVERAL DAYS

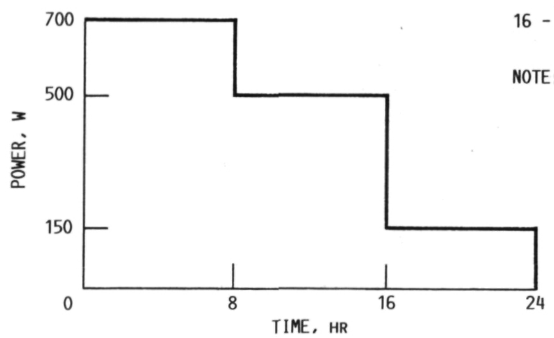


FIG. 3. - ROVER AVERAGED POWER PROFILE OF PV/STORAGE SYSTEM.

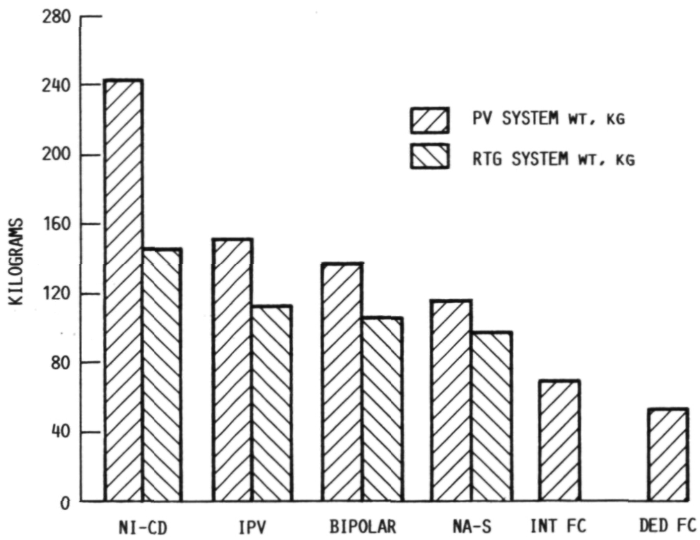


FIG. 4. - TRADE ANALYSIS 500W ROVER.

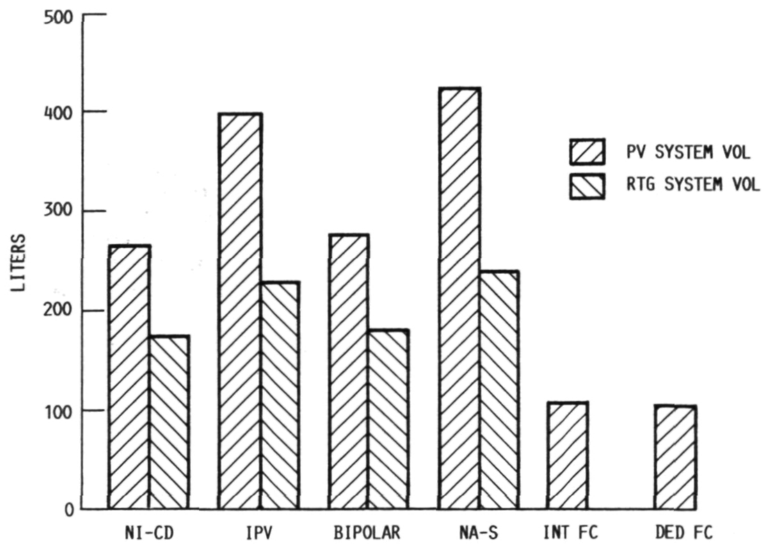


FIG. 5. - TRADE ANALYSIS 500W ROVER.

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